Design of TEL environment to develop Multiple Representation thinking skill

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Abstract: Multiple Representation thinking skill is one of the important skills for problem solving in Engineering domain. In this paper, we describe learning activities to develop multiple representation thinking skill in TEL environment. We proposed the learning activities like Decision Making Task Questions, Simulative Manipulation, and Guided Constructor in TEL environment to develop multiple representation skill. We conducted a post-test quasi-experiment to test the effectiveness of the learning activities developed. Quantitative results indicated that the activities are useful and that the mean ranks for the experimental group are significantly ($p<0.001$) higher than control group. The pedagogical framework is emerged from the steps followed to design the learning activities for MR.

Keywords: Multiple Representations, sub competencies, metacognitive processes

1. Introduction

Engineering students should be prepared to demonstrate pan-domain thinking skills (Mishra, Koehler & Hendrickson, 2011) such as problem estimation, problem posing, modeling, system thinking, and design thinking along with content knowledge. Thinking skills are cognitive processes that human beings apply for sense-making and problem-solving (Beyer, 1988). Multiple representations thinking skill is one of the important skills which are recommended for problem solving. Students should be able to mentally represent the constituents of problems to solve problem successfully (Jonassen, 2000). Multiple representation skill is defined as the ability of learners to encode appropriate information based on domain from given representations, select or construct appropriate representations for given problem and identify link between two representations (Ainsworth, 2006). Even though multiple representation skills are important students are not able to demonstrate these skills while solving the problems. Learners find it difficult to prepare these representations, they cannot identify similarity and discrepancies in representations and they cannot translate between different representations (Ainsworth, 2006)

In recent years, researchers have addressed the problem of teaching multiple representation thinking skills by developing technology enhanced learning environments by utilizing the affordances of modern information and communication technologies (ICT). They developed simulation based learning environments to teach multiple representation skill. Simulation based learning environments are designed to support learner to make correct relation between different representations (Ploetzner, et.al, 2009). Dynamically linked representations (van der Meij and de Jong, 2006) are designed to help students to relate different representations. These learning environments are mainly available at K-12 level and for science education. The learning environments to teach multiple representation thinking skills are not reported at tertiary level especially for engineering education.

The research goal of our paper is identification of learning activities in technology based learning environment to develop multiple representation skill among engineering graduates. In this paper we report the design and evaluation process of learning activities for multiple representation thinking skill. We designed learning activities for an Electronics Circuits course, which is part of all four-year undergraduate engineering programs in Mumbai University, India. Content for this study is selected from topic of BJT applications.

2. Process to design learning activities for multiple representation thinking skill

2.1 Identification of instructional strategies to develop MR

The first step of design process was to identify measurable learning outcomes (backward design-Wiggins & McTighe, 2005). We characterized multiple representation thinking skill in terms of measurable competency and then operationalized MR competency into measurable units. These measurable units are referred as ‘sub-competencies’ (Mavinkurve &Murthy, 2012). Sub-competencies are identified through content analysis of experts’ problem solutions. Multiple representation competency is operationalized into the following sub-competencies: Students should be able to 1) construct valid representations for given problem (MR1); 2) Identify consistency between the representations (MR2); 3) apply representations to solve problem (MR3).

The next step of design process was to decide the learning activities to help learner to attain these sub-competencies. In order to attain these sub competencies learner should be able to carry out the set of processes (Ainsworth, 2006). We identified these processes by applying qualitative content analysis method. We analyzed expert (N=5) problem solutions to know the processes to be performed to attain the sub competency. The problem given to expert is “*1mV signal is applied to the amplifier to get 1V output. The frequency range of signal is 100Hz to 100KHz.Draw suitable circuit, waveforms, using circuit calculate values of circuit components.*”

We first coded the steps of problem solving based on actions taken by experts. For example, the statement “Draw a circuit of two stage BJT-FET amplifier for given application” falls under MR1 sub-competency and decision is taken for identification of appropriate representation. The code assigned to this action is ‘Decide representations’. When these codes are examined it was found that some of the actions can be categorized under common heading. For each sub-competency of MR such types of actions were frequently seen. Common actions were clubbed together into category. It was found that for “MR1-construct valid representation” valid representations need to be identified and then drawn correctly. In order to achieve this desired outcome decision need to be taken based on conceptual understanding. Similarly for MR2-“Consistency between two representations” link between two representations should be decided based on concepts. Students will be able to decide connectivity between the representations based on their conceptual understanding. Both these actions require decision making in different conditions. For both these sub competencies decision task was clubbed into decision making category.

We found that for each category emerged from content analysis a regulation of thinking process is required. Monitoring and regulation of thought processes to ensure effective and consistent learning process is referred as metacognition (Schwartz, 2009). Hence we defined these categories as metacognitive processes (Biswas et.al, 2013). For sub competency of ‘MR1-construction of valid representation’, we found that experts apply decision making and they construct accurate representations. Metacognitive process of decision making and drawing consistent constructions is required for sub competency of MR1. For ‘MR2- identification of consistency between representation ’expert decide the common and supporting points between the representations. This is decision making process. They establish link between the two representations based on domain knowledge. This metacognitive process is referred as complementary thinking (Ainsworth, 2006). For sub competency of ‘MR3-Application of representations to solve problem’, decide part of representation useful in problem solving and implement the solution process based on selected representation. This need decision making as well as concept integration. The main metacognitive processes identified from experts’ solutions to attain MR are decision making, concept integration, construction of representation and complementary thinking.

Decision making involves an iterative series of divergent-convergent thinking in which students need to generate many options based on the set of information available, evaluate them based on domain knowledge expertise (Gresch, 2012). Concept integration process expects learner to select appropriate pieces of information based on domain knowledge (Chen et.al, 2011). Complementary thinking metacognition process (Ainsworth, 2006) expects learners to create referential connections between the corresponding elements to construct coherent knowledge structures (Seufert, 2003). For example in circuit problems students should be able to create connections between the components values and waveform parameters which will help them to understand function of circuits or application of given circuit. Drawing of consistent construction metacognitive process expects learners to select correct elements, arrange these elements or connect these elements to make meaningful constructions (Zacks & Tversky, 1999).

Our goal is that the learning activities should be able to trigger these metacognitive processes by incorporating appropriate instructional strategies (Zimmerman, 2007). We reviewed research work on learning science principles and instructional strategies to find the recommended strategies for each metacognitive process. Decision making can be triggered using series of deep reasoning questions (Aurisicchio et al., 2007) as well as providing options for selection. Decision making process can be triggered using formative assessment in which series of deep reasoning questions were developed at decision step and feedback provided to guide learner for self-monitoring to aid decision process (Mavinkurve & Murthy, 2014). Concept integration is triggered by providing guided experimentation opportunity to learners (Mavinkurve &Murthy, 2014). Dyna-linked multiple representations (concurrent changes over time) with guided questions help learner to make connections between two representation (Van der Meij and de Jong, 2006) to develop complementary thinking process. Learner generated drawing (Van Meter & Garner, 2005) is recommended strategy for helping learners to construct representations. In this strategy learners are provided with key elements of constructions and guided questions are provided to connect the key elements for developing appropriate constructions.

2.2 Learning activities based on instructional strategies of MR

The instructional strategies identified in previous section are implemented through learning activities of TEL environment. In order to realize the instructional strategies within the TEL environment, we use instructional scaffolding (Bull et.al,1999) as a base to design the learning activities. Instructional scaffolding is two-way interaction between the learner and the learning environment in such a way that the learner is actively engaged in the learning activities. Interactivity design principles (Mayer, 2009) are applied while designing learning activities to ensure two way process of instructional scaffolding.

We created learning activity implementing formative assessment for decision making using guided activity principle and feedback principle. Learning activity that implement the formative assessment strategy is referred as *Decision Making Task Questions (DMTQ)*. DMTQ is a conceptual question in which various choices are given to students to include all plausible decisions related to the question. For each choice, feedback is designed considering feedback principles of effective feedback. Feedback works as prompt in decision making process which guides students to reasoning of wrong answers and pointer to correct answer. We designed *Simulative Manipulations* as a learning activity in TEL environment to provide experimentation opportunity to students. We created Simulative Manipulation using guided activity principle. In Simulative Manipulation, students are allowed to select different parameters and changes are shown as graphs or waveforms. Feedback is provided in the form of text or question prompt.

Table 1: Steps to develop learning activities for MR competency

Sub competency	Expert actions	Metacognitive processes	Theoretical Basis		Interactivity Design principles (to operationalize strategy to TEL environments)	Learning activities
			Learning science principles	Instructional Strategies		
MR1-Construct representations-	Apply concepts for decision making	Decision Making	Planning, monitoring and evaluation Self-regulations	Formative assessment question and feedback	Guided activity	DMTQ

We used feedback principle to design feedback of Simulative Manipulation (SM). SM essentially included simulations of graphs or waveforms based on various input values. Theses simulations are dynamically linked followed by guided question to help learner to make links between the corresponding constituents of representation. We created 'Guided Constructor' learning activity to implement strategy of learner generated drawing .In this activity the key elements of constructions are provided as tool box. This tool box guides the learner for selection in construction process. Learners are guided through the conceptual questions and feedback for connection of key elements. Formative assessment strategy helps learners for verification of accuracy of final connections. Table 1 shows the steps of development of learning activities for MR1 sub competency.

3. Learning material for analog electronics to develop MR

We selected concept of BJT operating regions and its application as switch. Fig. 2 shows an example of a DMTQ learning activity which directs user to decide the relevant representation for given problem.

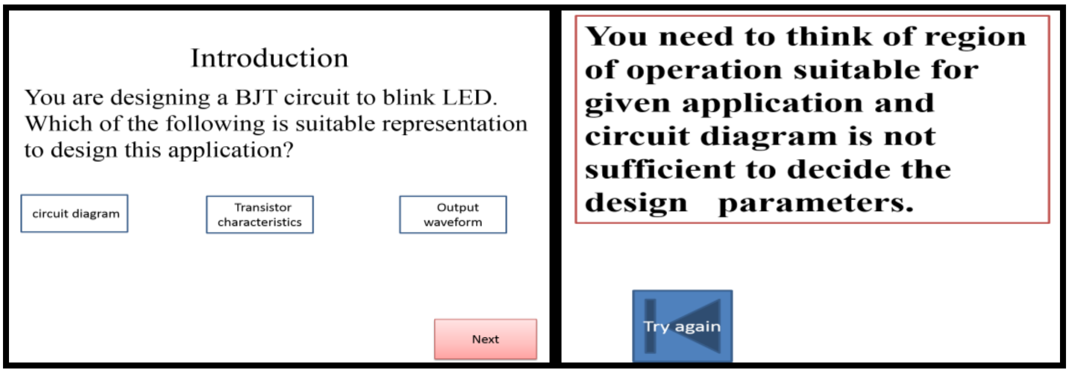

Fig 2. DMTQ *learning* activity for Multiple Representation

Guided constructor activity contains the tool box of key elements such as load line, saturation region, cut-off region as shown in fig 3. Guided questions are provided to help learner to use these key elements to draw constructions and mark relevant labels of construction.

Fig 4 represents simulative manipulation learning activity in which we showed two representations such as circuit diagram and load line characteristics. When learner will vary values of resistor (RB) he/she will be able to see changes in load line characteristics and switching conditions of LED.

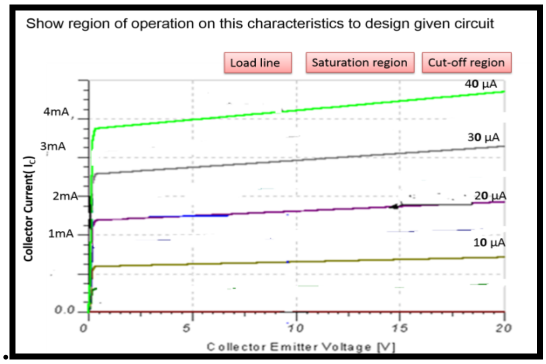

Fig 3. Guided Constructor

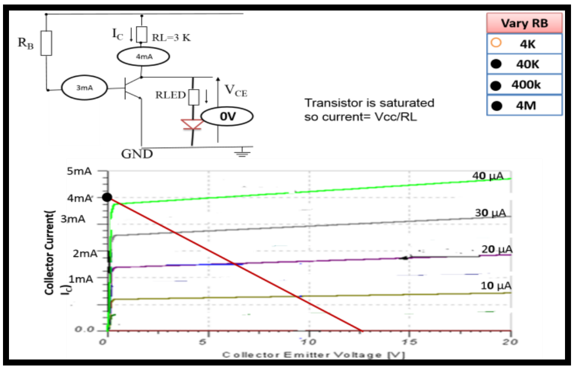

Fig.4.Simulative Manipulation

4. Learning effectiveness testing to develop MR

4.1 Methodology

We conducted a two group post-test quasi-experiment to test the effectiveness of the Learning activities developed for MR thinking skill.

Sample: Our sample consisted of students from 2nd year Electronics engineering (N=53). Students had some familiarity with the content in the visualization, as they had learnt it in the theory course on the same topic. They were also familiar with using ICT materials.

Procedure: Students were randomly assigned to two groups. The experimental group consisted of 27 participants and the control group had 26 participants. The equivalence between the two groups was tested on basis of their previous semester's grades and no significant difference was found between them ($t=0.14$, $p=0.44$). Two sets instructional materials on the same topic were developed. This experiment is conducted in teacher driven mode i.e. teacher used learning material to teach the topic of BJT application as switch. For experimental group teacher used TEL based instructional material to explain concept of transistor switching. Instructor showed DMTQ and asked students to write their answers and then showed feedback for each selected answer. In control group PPT slides with same diagrams, concepts are applied. But students were not given questions instead instructor explained them which is correct representation why is it a appropriate representation etc. Students in both groups were taught by same teacher for 30 minutes, after which they attempted the post-test. The test was based on application of transistor as switch but the application was for development of digital test signal was given in post-test.
Instrument: To assess the development of students' multiple representation competency (and sub-competencies) we used assessment rubrics, which had a 4-point scale: 0-Missing, 1- Inadequate, 2-Reasonable but needs improvement, 3-Good. Each rubric item corresponded to one sub-competency (MR 1-3).For e.g. In order to assess MR1 the target performance level was described as constructions are valid as per problem requirement and all primary and secondary details are present in the constructions. These rubrics were validated prior to the experiment. Inter-rater reliability testing was found to give 94% agreement between 3 instructors.

4.2 Results

The scores on the post-test are ordinal data; hence we used a Mann-Whitney U-test for analysis. The mean ranks for each sub-competency for the two groups are shown in Table 2. The results show that the mean ranks for the experimental group are significantly ($p<0.001$) higher in each sub-competency. We inferred that learning activities proposed in our study helped learner to develop MR competency for topic of BJT application

Table 2: Comparison of experimental group and control group MR sub-competency scores

Sub competency	**Group**	**N**	**Mean score**	**Mean Rank**	**z**	**p**
MR1	Control	26	0.88	17.04		
	Expt	27	1.85	36.59	4.59	<0.01
MR2	Control	26	0.26	16.52		<0.01
	Expt	27	1.51	37.09	4.83	
MR3	Control	26	0.26	17.79		<0.01
	Expt	27	1.25	35.87	4.25	

5. Conclusion and future work

We focus on teaching of multiple representation competency through TEL based learning environments. In this work we characterized MR into measurable competency which is further operationalized into sub-competencies. We developed learning activities of TEL based system to trigger essential metacognitive processes required to attain MR sub competencies. We proposed the learning activities like Decision Making Task Questions (DMTQ), Simulative Manipulation(SM), and Guided Constructor (GC) in TEL environment to develop MR. In this paper we started with sub competencies of MR and identified the metacognitive processes applied by experts to attain sub competencies. We then reviewed literature on learning science principles to find the learning strategies to trigger these metacognitive processes. We then implemented these strategies into learning environment using Interactivity Design principles.

A pedagogical framework is emerged from the steps we followed to develop learning activities of MR. We tested these activities in instructor driven mode; it is required to study effectiveness of these activities in self-learning TEL environment. Quantitative result indicated that the activities are useful but how they help learner in MR development process need to be investigated. We plan to conduct student's problem solving interviews once they learn through our system and will find the correlation between the learning activities designed by us with development of MR thinking skill.

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